VEKTRON® 6913 GASOLINE ADDITIVE NO_x EVALUATION FLEET TEST PROGRAM

NOTE: This document has been edited to reflect changes made to the original fleet test protocol during the test execution.

I. INTRODUCTION

In July of 1997, a “Protocol for the Reduction of NO_x Through the Use of Vektron 3000 Gasoline Additive” was submitted for approval to the State of New Hampshire, Department of Environmental Services, Air Resources Division. Based on three separate multi-vehicle (34 vehicles total) fleet tests, comparison of results to the Mobile 5a model, and application of engine technology and fuel-switching discount factors, this protocol proposes that the use of Vektron 3000 series gasoline additives would reduce emissions by 2.31 tons of NO_x per 1 million gallons of gasoline versus NO_x emissions from 1 million gallons of a conventionally additized gasoline.

After several weeks of public debate and comment, Infineum was advised by the State that the protocol had been approved with conditions. In the State’s opinion, while the three fleet tests cited in the protocol demonstrated a real NO_x emissions reduction through the use of Vektron 3000, these fleet tests did not sufficiently support the 2.31 tons of NO_x reduction proposed. Instead, through application of several additional discount factors as specified in the conditions, a reduction of 0.17 NO_x tons per 1 million gallons of Vektron 3000 additized gasoline was allowed by the State.

Since New Hampshire’s decision reduced the cost effectiveness of this NO_x reduction technology, Infineum proposed to collaborate with the US Environmental Protection Agency (US EPA) Office of Mobile Sources in the design and execution of additional fleet testing with the Vektron 3000 technology. Such fleet testing would more accurately quantify the NO_x reductions realized from the use of Vektron 3000 technology. The State of New Hampshire and the US EPA have accepted Infineum’s proposal for additional fleet testing.

The following fleet test program resulted from several months of collaboration between the US EPA Office of Transportation & Air Quality (OTAQ) and Infineum, with input and advice from major automotive manufacturers.

The objective of the proposed fleet test was to validate and quantify the NO_x reductions achieved through the use of Vektron 6913 gasoline additive to the satisfaction of the US EPA.

II. TEST DESIGN MATRIX

In order to achieve the program objectives, a number of experimental designs were considered. A design built up from 2 standard cross over designs was determined to be the most effective choice for providing statistically reliable estimates of the NO_x reductions that would result from the use of Vektron 6913.

The basic design structure consisted of 7 vehicle groups covering a number of the most popular vehicle models in today’s vehicle fleet. Each vehicle group contained four vehicles (28 total vehicles). Each vehicle was driven 1,000 miles after acquisition followed by qualification checks including regulated emissions levels and vehicle oil consumption. Based on the qualification check results, the vehicle's inclusion in the test program was determined.

This design required two different fuels, reference fuel and test fuel, both formulated with the same unadditized base fuel as detailed in Section V. Fluids / Fuels. These fuels were evaluated based on the following matrix:

Test Design Matrix

Vehicle	Run 1	Run 2
1	Reference fuel	Test fuel
2	Test fuel	Reference fuel
3	Reference fuel	Alternating fuels
4	Alternating fuels	Reference fuel

Alternating fuels was defined as switching between reference fuel and test fuel at each fuelling point during the run as described in Section V. Fluids / Fuels.

III. VEHICLE SELECTION AND ACQUISITION

Vehicles were selected to be a representative sample of the most popular vehicles in today's vehicle fleet. The selection considered engine type, model year (one vehicle from each of the last 6 years, two from 1999), and certification to specific emissions standards (light duty truck or light duty vehicle and LEV or non-LEV).

Test Vehicles

Vehicle Type	Power Plant	Fuel System	Transmission	Model Year	Certification
Ford Explorer	4.0L V-6	MPFI	Automatic	'99	LEV LDT
Chevrolet C-1500	5.7L V-8	MPFI	Automatic	'99	LDT
Honda Accord	2.3L I-4	MPFI	Automatic	'98	LEV LDV
Ford F-150	4.6L V-8	MPFI	Automatic	'97	LDT
Ford Escort	1.9L I-4	MPFI	Automatic	'96	LDV
Dodge Caravan	3.3L V-6	MPFI	Automatic	'95	LDT
GM Buick LeSabre / Olds 88 Royale	3.8L V-6	MPFI	Automatic	'94	LDV

During the early stages of vehicle acquisition, SwRI informed Infineum that the 1999 Ford Explorer 4.0L specified in this test program was only available as a LEV. Because 3 LEVs were not needed in this test, Peter Hutchins from the US EPA was consulted on this dilemma. Peter had two recommendations:

- Substitute the Ford Explorer with a Ford Ranger 4.0L if it is not a LEV.

- Keep the Explorer as a LEV and switch the Silverado LEV back to a C-1500 5.7L, which is not a LEV. (The C-1500 had originally been considered in the test program due to its high sales volume in the US but removed from the list when the US EPA asked that another LEV be included in addition to the Honda Accord.)

These recommendations were discussed with the US based project team since it involved US car sales volumes and preferences. The second option was preferred since it would keep a SUV on the test list plus it would once again include one of the most popular vehicles in the US, the C-1500, in the test. SwRI also confirmed that the Ford Ranger 4.0L had the same engine as the Ford Explorer so it was also a LEV. Thus the Silverado was substituted with the Chevrolet C-1500 5.7L V-8 non-LEV vehicle. The 2 LEVs in the test became the Explorer and the Honda Accord.

The Chrysler minivan chosen for the test was the Dodge Caravan.

The purchase / lease of 4 ’94 GM Pontiac vehicles proved to be difficult. In fact, it was difficult to find one ’94 GM Pontiac that fit the test specifications. This issue was discussed with the US EPA (Peter Hutchins) and it was decided that any ’94 GM 3.8L V-6 model that fit the test specifications would be acceptable. Therefore, three of the vehicles were Buick LeSabres (GP-1, GP-2, GP-3) and one vehicle was an Oldsmobile 88 Royale.

The US EPA also agreed that differences in car styles (wagon vs. sedan vs. 2-door hatchback) would broaden the spectrum of vehicles tested. Therefore, minor style differences exist in some of the vehicle groups.

Acquisition criteria included a minimum odometer mileage accumulation of 15,000 miles and a maximum of 75,000 miles.

Some difficulty was also encountered in obtaining some of the older model vehicles at or below 75,000 miles. Therefore, the odometer mileage upper limit was extended and these vehicles were accepted in the test as long as the vehicles meet the qualification criteria specified in the next section. The following vehicles in the test had extended odometer mileage:

Vehicle Type	Vehicle Test Code	Odometer Mileage at Start of Test
’96 Ford Escort	FE-4	79,225
’95 Dodge Caravan	DC-1	75,214
’95 Dodge Caravan	DC-2	96,790
’95 Dodge Caravan	DC-3	105,646
’95 Dodge Caravan	DC-4	81,194
’94 Buick LeSabre	GP-1	88,162

IV. VEHICLE QUALIFICATION CHECK

Following acquisition each vehicle accumulated 1,000 miles using reference fuel and underwent the following qualification checks:

- Vehicle oil consumption was not to exceed 250 ml as measured by SwRI’s Standard Oil and Filter Changing and Weighing Procedure (Appendix 1).

- If the vehicle met the above criterion, then the vehicle was tested for regulated emissions using the FTP test cycle using tank fuel (i.e., reference fuel in the qualification runs). The FTP emissions were not to exceed 125% of standard values for each vehicle.

The vehicle oil consumption agreed to for the qualification check was not a standard but rather an estimated oil consumption that would prevent the inclusion of high oil burning vehicles in the test. SwRI had some concerns with the initial 150 ml limit. This was discussed with Peter Hutchins of the US EPA and the limit was changed to 200 ml. Once qualification checks were started, it became evident that 200 ml was tight for some of the vehicles to meet. The US EPA was not concerned with these results and agreed to extend the oil consumption limit further to 250 ml for the 1,000-mile qualification check. As the older model vehicles started qualification ('94s and '95s), this oil consumption was extended even further based on the understanding that these vehicles will have higher oil consumption due to higher odometer mileage. One of the '95 Chrysler Minivans (Dodge Caravan / DC-2) had and oil consumption of 271 ml while two of the Buick LeSabres surpassed the 250 ml limit (GP-1 @ 378 ml, GP-3 @ 258 ml).

V. FLUIDS

Fuels

Unadditized fuel approximated the physical and chemical specifications recently published by a number of fuel manufacturers in California, CA RFG Phase 2 without oxygenates. The specification is shown in the table below:

Unadditized Fuel Specification

Parameter	Units	Range	Actual C of A
Sulfur	**ppm**	**20 – 40**	23
Aromatics	**vol %**	**22 - 32**	25.8
Olefins	**vol %**	**5 – 15**	7.9
Vapor Pressure	**psi**	**7.0 – 7.8**	7.6
T10	**°F**	**124 – 144**	142
T50	**°F**	**190 – 210**	205
T90	**°F**	**322 – 342**	337
End Point	**°F**	**420 max**	381
Oxygenates		**None**	0.0
Octane, (R+M)/2		**87 min**	90.2

In order to produce fuel with minimum deposit forming tendencies and to remain within commercial limits, the parameters used by the US US EPA in the regulations supporting the Clean Air Act Amendments of 1990, Section 211(l), to determine fuel deposit forming severity were specified. In order to meet these specifications, a regular grade octane was not achievable. Since the US US EPA does not recognize octane as a fuel deposit forming severity factor, the octane was only specified to meet minimum commercial limits.

Two fuels were used in this program:

Test Fuels

Reference fuel	**Unadditized fuel + 154 PTB Vektron 2864**
Test fuel	**Unadditized fuel + 234 PTB Vektron 6913**

Please note that Vektron 2864 has been rebranded to Infineum F7721.

Each fuel delivered the same detergent and the same amount of detergent active ingredient. However, the more traditional synthetic carrier in the reference fuel additive was replaced with Vektron 1200 in the test fuel additive.

Unadditized fuel was blended with either Vektron 2864, a conventional detergent with synthetic carrier, or Vektron 6913, a conventional detergent with Vektron 1200. Approximately sixty percent of the unadditized fuel was blended with Vektron 2864, forty percent with Vektron 6913. The total program fuel consumption did not exceed 30,000 gallons.

The reference fuel and test fuel were each blended and stored in a single location under a nitrogen blanket with minimal exposure to ambient conditions.

All vehicles were fuelled into the tank at the mileage accumulation dynamometers (MADs), i.e., no continuous fuelling. All vehicles were fuelled below a quarter tank level at a convenient interval in the test cycle. This fuelling was calculated using fuel tank size, mileage accumulation, and vehicle fuel economy as determined by the Department of Transportation regulations.

Fuel switching in the ‘alternating fuel’ scheme of the test matrix specifically referred to alternating between reference fuel and test fuel each time fuelling occurred.

Motor Oil

All vehicles used a single batch of the same motor oil. The viscosity grade was SAE 5W-30. Service classification was API SJ and ILSAC GF2.

All vehicles had an oil change upon acquisition followed by another change immediately after meeting the quality check criteria. Oil drain intervals during the mileage accumulation were 4,000 miles (i.e., at the mid-point and end of every run). Oil changes at the end of the runs were performed before the emissions testing.

VI. MILEAGE ACCUMULATION

Mileage Accumulation Dynamometers

The MADs used for this program were single roller, 48 inches in diameter, and fully automated. The MADs were capable of controlling critical engine parameters to match on road conditions.

Distance

Each run was 8,000 miles. This 8,000 miles approximated the total mileage that an average vehicle could accumulate during a typical ozone season.

Each vehicle ran no more than 16 hours per day with an 8 hour soak time, as accepted by US EPA and the California Air Resources Board (CARB) in previous Coordinating Research Council (CRC) programs. In addition, no vehicle was out of service for longer than a 2-day period.

Cycle

The mileage accumulation cycle was performed according to 40 CFR Ch. 1 (7-1-94 Edition) § 86.084-26 (Appendix 2) and as modified in the Mobile Source Air Pollution Control (MSAPC) Advisory Circular A/C No. 37-A driving mode 70 mph top speed (Appendix 3).

VII. EMISSIONS TESTS

In the constant fuel scheme (i.e., reference fuel only or test fuel only) each vehicle was tested using FTP-75 and the fuel that was in the tank during mileage accumulation. In the alternating fuel scheme, emissions testing was done ONLY on test fuel. If mileage accumulation ended with reference fuel in the vehicle fuel tank, the fuel was changed to test fuel for the emissions testing. Regulated emissions (NO_x, CO, HC) were tested in duplicate. Additional tests were run if necessary as judged using the CRC Auto / Oil Protocol (Appendix 4).

Upon completion of the FTP-75, each vehicle was tested for all regulated tailpipe emissions under US06 and Highway Fuel Economy Test (HFET) cycle. US06 and HFET testing was performed in duplicate. As with the FTP-75, triplicate HFET tests were run if necessary as judged using the CRC Auto / Oil Protocol.

All emissions testing were performed at the following intervals during the test:

- Start of Run 1 (i.e., SOT)
- End of Run 1 / start of Run 2
- End of Run 2 (i.e., EOT)

Representative Hydrocarbon Evaporative Emissions testing was performed on one late model vehicle (i.e., '99 Ford Explorer). Both hot soak and multi-day diurnal procedures were performed using both test fuels to insure that there was no additive contribution to evaporative emissions.

The running loss emissions test was not available at SwRI and would require considerable time beyond the limitations placed on this program to put into operation.

VIII. DATA ANALYSIS

<u>Mixed Effects Model Anova</u>

The analysis was data driven to be flexible. In it's simplest form, the matrix could simply be analyzed using Analysis of Variance (ANOVA), using a mixed model approach. This design had an emphasis on simplicity since only two conditions existed within each vehicle (reference fuel or test fuel). These were the primary effects that will be tested. During the development of the design, a power analysis was performed to determine the chance of seeing an effect of a given size, based on the sample size and design matrix. A number of terms were measured, including interactions, and possible carryover.

<u>Outliers</u>

If data was determined to be an outlier (using standard methods), an attempt was made to assign a physical cause to the outlier. If the cause could not be determined, the data analysis was performed with and without the outlier.

<u>Transformation</u>

Since ANOVA assumes a normal distribution of the residuals, and the literature suggests that NO_x require a transformation, a Box-Cox analysis was performed to determine the best transformation. The data may require a log transform.

<u>Analysis Flexibility</u>

As stated the analysis was data based and 'followed' the data A very powerful idea in statistics is *convergence.* Convergence occurs when more than one methodology is applied and compared to build understanding and confidence in a finding. Many analyses were done to these data to improve understanding and confidence. Both internal and external consultants, such as the US EPA, were used.

IX. SUMMARY

The program described above was designed to provide statistically verifiable NO_x reductions attributable to Vektron 6913 under various consumer fuel purchasing patterns. The program used a representative fleet of vehicles used under normal driving conditions to model real world emissions reductions. The vehicles were validated and maintained in accordance with manufacturers' recommended practices.

The fuel formulation used in this program represented the best estimate of the direction of future fuel formulations. This clean formulation mitigated any fuel effects that could impact the results.

The additive used in the reference fuel represents current state of the art cleanliness additive technology. The experimental additive used in the test fuel of this program maintained all the cleanliness attributes of the reference fuel additive while providing NO_x emissions reductions.

This program was designed with input from leading experts in the additive, automotive and regulatory communities in the United States using the latest statistical experimental design techniques. This program, as shown above, represents the highest degree of validity achievable under given constraints.

X. RESULTS COMMUNICATION

Results of the data analysis, as specified in Section VIII, were reviewed by Infineum and supplied along with the emissions data to the US EPA OTAQ.

Raw data is owned by and resides with Infineum.